MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2 2022/2023 (TERM ID 2220)

ERL2036 – ELECTRIC MACHINES AND POWER SYSTEM

(BSc IR)

7 JULY 2023
9.00 a.m - 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of **9** pages including the cover page and Appendix. There are **FOUR** questions in this paper.

2. Attempt **ALL** questions. All questions carry equal marks and the distribution of marks for each question is given.

3. Some useful formulae are given in the Appendix section.

4. Please write all your answers in the Answer Booklet provided.

Question 1

(a) Identify **TWO** statements that are **TRUE**:

A. Motor is an electric machine that converts mechanical power to electrical power through the action of magnetic field and rotation.

B. Transformer is a static device with two or more windings, which converts electrical power from one voltage level to another voltage level at the same frequency.

C. A motor is supplying 75 N-m of torque to its load, where the shaft of the motor is turning at 1600 revolution/min. The corresponding mechanical power supplied to the load is 16.84 hp.

D. Figure Q1A depicts a wire carrying a current in the presence of a magnetic field, with a magnetic flux density of 0.5 T, directed into the page. The wire has a length of 1.25 m, and carries a current of 0.8 A in the direction from the bottom to the top of the page. The induced force is 1.5 N, directed to the right.

[2 marks]

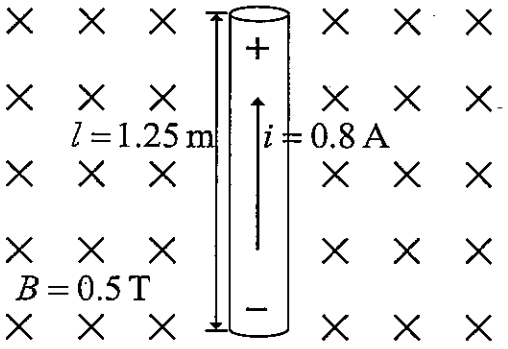

Figure Q1A

(b) Figure Q1B illustrates a ferromagnetic core structure with a relative permeability of 1800. A current $i = 2.75$ A flows through a 600-turn coil wrapped around the left leg of the core. The depth of the core is 8 cm, and the other dimensions of the core are indicated in the diagram. Due to the fringing effect, the effective area of the air gap is 12% larger than the physical core area.
(Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H/m)

(i) Determine the total reluctance of the core structure. [5 marks]

(ii) Calculate the flux density at the bottom of the core. [4 marks]

(iii) Find the magnetic field intensity of the air gap. [3 marks]

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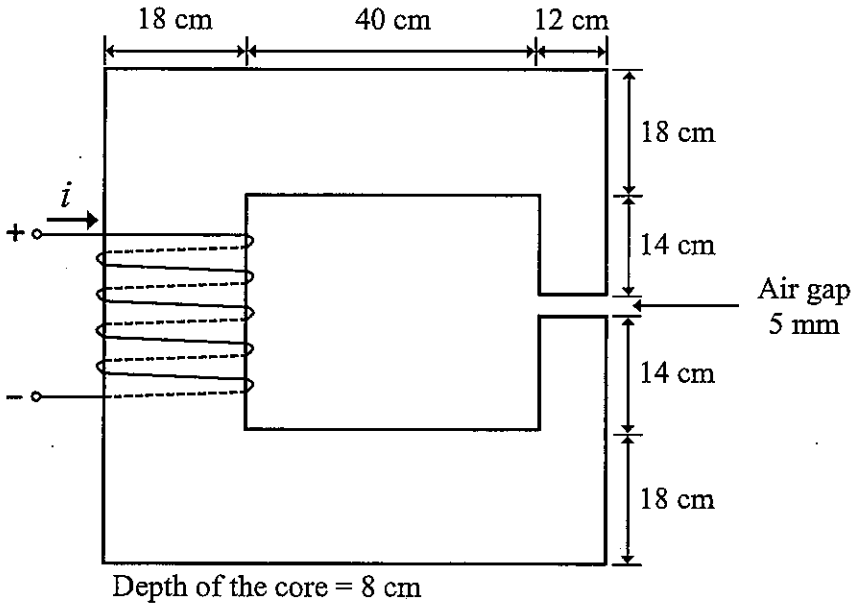

Figure Q1B

(c) A balanced three-phase power system consists of an ideal Y-connected generator with a phase voltage $\mathbf{V}_{an} = 240\angle 20°$ V. A positive phase sequence is assumed for the source voltages. The generator is connected through a three-phase transmission line to a Y-connected load with a per-phase impedance $\mathbf{Z}_Y = (18 + j32)\ \Omega$. Given that the transmission line is assumed negligible.

(i) Determine the line currents $\mathbf{I}_a$, $\mathbf{I}_b$, and $\mathbf{I}_c$. [4 marks]

(ii) Find the line voltages $\mathbf{V}_{ab}$, $\mathbf{V}_{bc}$, and $\mathbf{V}_{ca}$. [4 marks]

(iii) Calculate the total real and reactive powers consumed by the Y-connected load. [3 marks]

Continued...

Question 2

(a) Unlike the ideal transformer, real transformers experience losses during operation. Briefly describe the following losses associated with real transformers and how they are represented in a transformer equivalent circuit:

(i) Copper losses

(ii) Eddy current and hysteresis losses

(iii) Leakage fluxes

(iv) Finite permeability of the core

[8 marks]

(b) An ideal transformer is rated at 3300/110 V, 9.9 kVA, and has 80 turns on the secondary side. Determine the number of turns on the primary side, as well as the primary and secondary currents.

[4 marks]

(c) Figure Q2 shows an approximate equivalent circuit diagram of a transformer, referred to the secondary side.

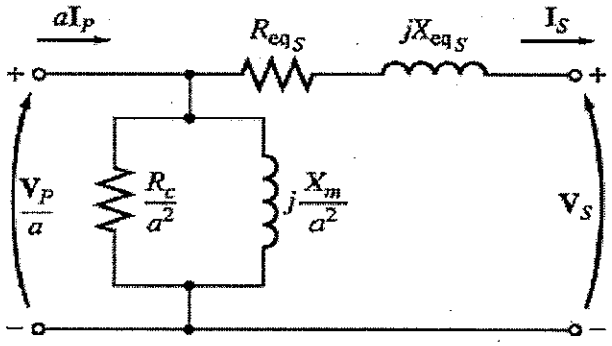

Figure Q2

(i) Determine the copper and core losses of the transformer if $V_p = 240kV$, $I_s = 350A$, $R_C = 640k\Omega$, $R_{eqS} = 0.4\Omega$ and $a = 16$.

[5 marks]

(ii) Evaluate the performance of the transformer in terms of voltage regulation and efficiency if $V_S = 13.8kV$ and $P_{out} = 4200kW$.

[4 marks]

(d) With the aid of a diagram, briefly explain the construction of a single three-phase transformer. State its advantages over construction using three single phase transformers.

[4 marks]

Continued...

Question 3

(a) There are **FIVE** major types of DC generators, classified according to the manner in which their field flux is produced. Briefly describe these **FIVE** types of DC generators.

[5 marks]

(b) A 4-pole, 1500rpm lap wound DC shunt motor with total number of conductors $Z = 400$ develops a mechanical torque $\tau = 36.6056Nm$ at an armature current $I_A = 45A$. Determine the induced voltage E_A and flux per pole ϕ in the motor.

[5 marks]

(c) Figure Q3 shows a circuit diagram of a separately excited DC generator. The generator has a field voltage of 120V and is running at 1800rpm to produce an induced voltage of 80V and delivers an armature current of 50A.

(i) Determine the field current I_F and the terminal voltage V_T.

[4 marks]

(ii) Deduce the input power P_{in} and the output power P_{out} if the rotational losses $P_r = 120W$ and stray losses $P_{stray} = 0W$.

[7 marks]

(iii) Evaluate the performance of the generator by means of its voltage regulation and efficiency.

[4 marks]

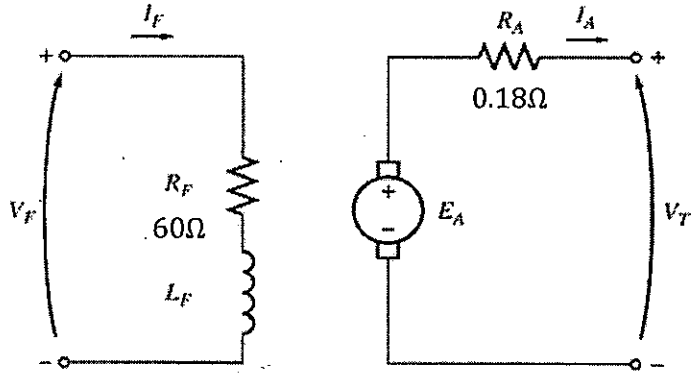

Figure Q3

Continued...

Question 4

(a) Figure Q4A shows the one-line diagram of an electrical power system. The ratings of the various components in the power system are given as follows:

Generator, G1:	300 MVA, 60 kV, $R = 10$ %, $X = 90$ %
Generator, G2:	500 MVA, 60 kV, $R = 5$ %, $X = 95$ %
Transformer, T1:	200 MVA, 60/360 kV, $R = 2$ %, $X = 15$ %
Transformer, T2:	160 MVA, 540/64 kV, $R = 2$ %, $X = 10$ %
Motor, M:	100 MVA, 32 kV, $R = 12$ %, $X = 85$ %

The transmission line has an impedance of $(15 + j42)$ Ω, and the static load impedance is $(2.25 + j5.3)$ Ω. Consider a base apparent power of 300 MVA and a base voltage of 60 kV at the generator side.

(i) Determine the base voltages and impedances in Regions 1, 2 and 3. [5 marks]

(ii) Sketch the impedance diagram of this power system, and clearly indicating all the impedances and their values in per-unit (p.u.) quantities. [8 marks]

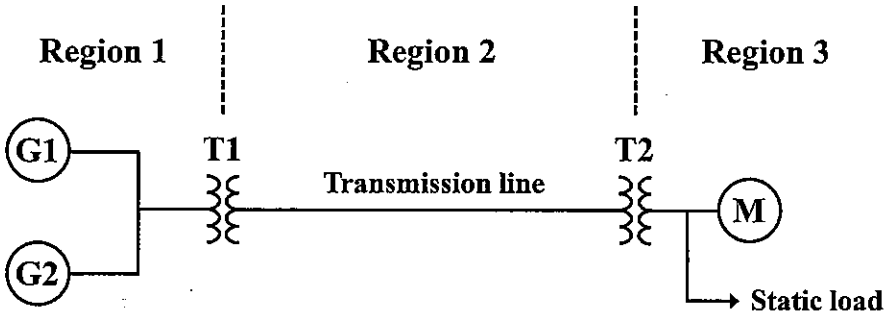

Figure Q4A

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(b) For a power distribution system as shown in Figure Q4(b), protective devices (P1, P2, P3, ... P10) are deployed at subfeeders to protect customers (A, B, C, D, E, F) within a community from overload current conditions.

(i) Briefly explain **THREE** basic requirements of protective devices. [3 marks]

(ii) Referring to the fault locations indicated in Figure Q4B, identify the customer(s) who will be affected by the overcurrent fault. Justify your answer for each case.

- Fault 1
- Fault 2

[4 marks]

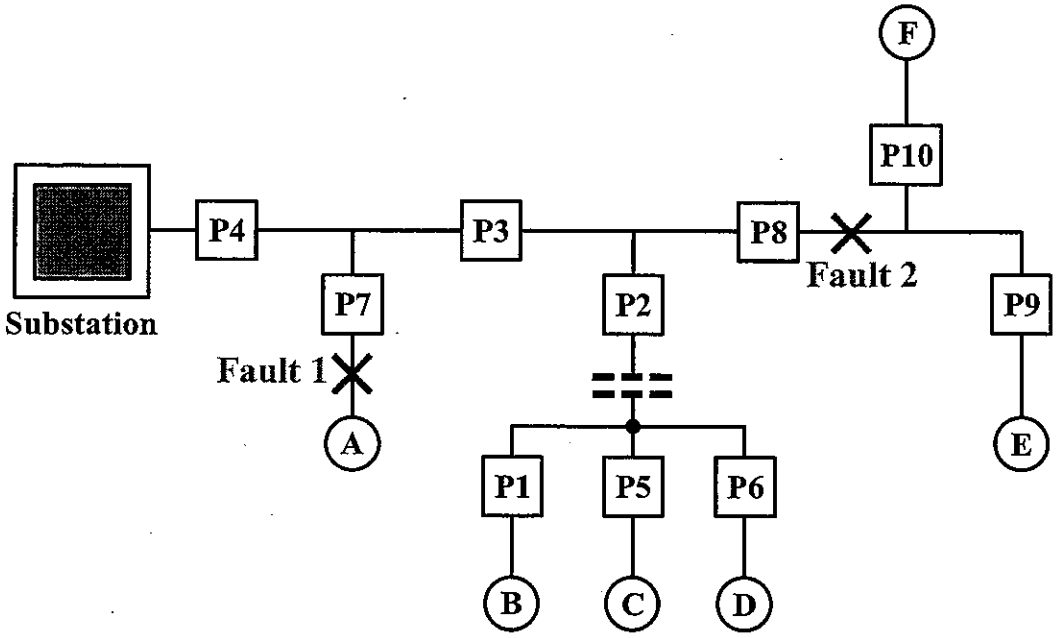

Figure Q4B

(c) Figure Q4C depicts the time-delay characteristic of a CO-8 Inverse Definite Minimum Time (IDMT) overcurrent relay, which is used to protect a distribution feeder in an electrical power system. The current tap settings of the IDMT relay are available at intervals of 0.5 A. The relay is connected to a 600:5 current transformer and a circuit breaker, and is set to operate when the load current on the feeder exceeds 540 A.

For a chosen time-dial setting of 3, determine the operating time of the relay for a fault current of 2000 A. [5 marks]

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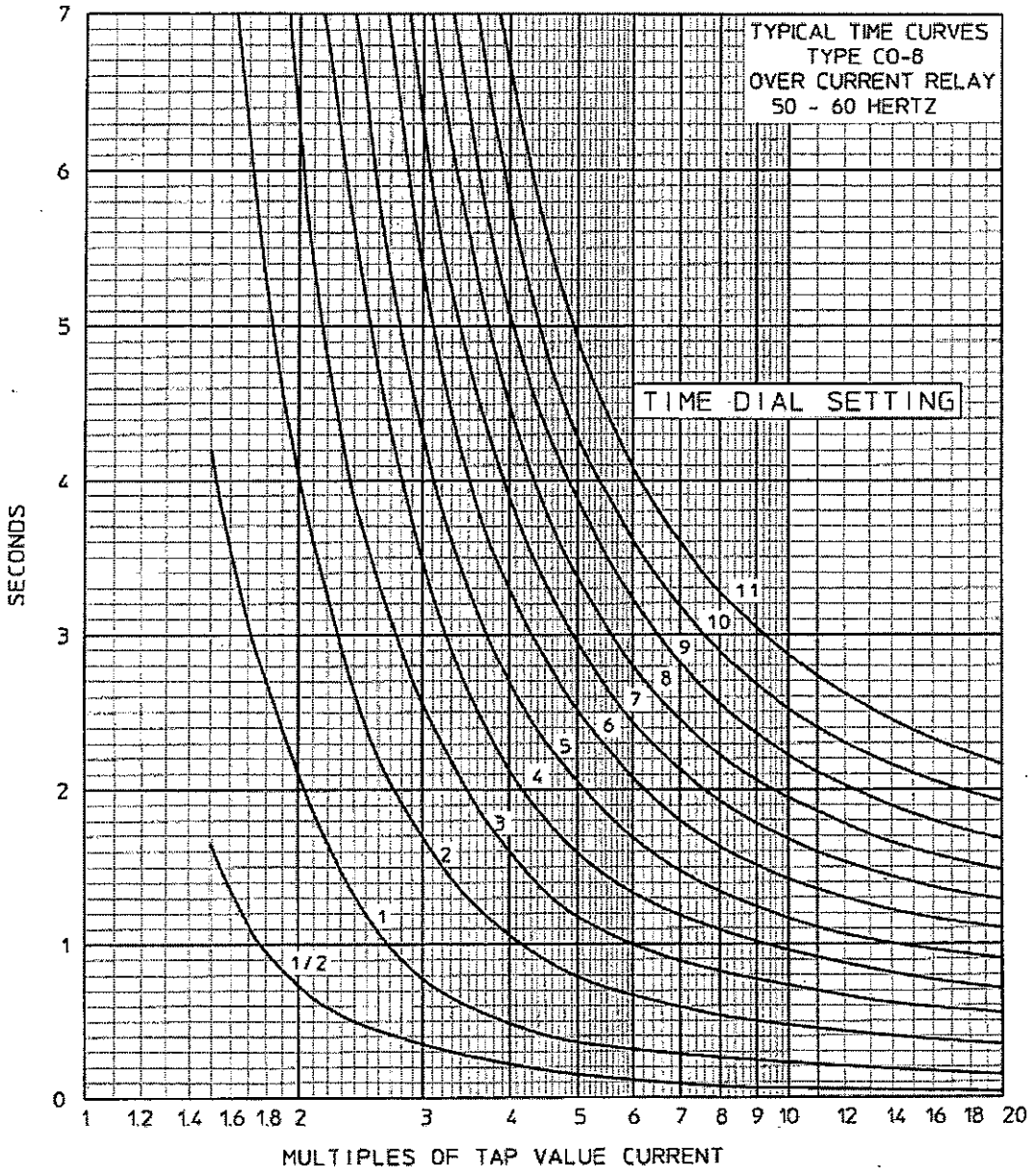

Figure Q4C

End of Questions

APPENDIX

Magnetic Circuits

$$H = \frac{Ni}{l_c}$$

$$B = \mu H = \mu_0 \mu_r H$$

$$\phi = BA$$

$$\Re = \frac{l_c}{\mu A}$$

$$\mathcal{F} = Ni = \phi\Re = Hl_c$$

$$\mathcal{F} = ilB \sin\theta$$

$$e_{ind} = vlB \sin\theta_1 \cos\theta_2$$

$$P = \tau\omega$$

Three-Phase Circuits

Y-Connection: $I_L = I_\phi,\ V_L = \sqrt{3}V_\phi \angle 30°$

Δ-Connection: $V_L = V_\phi,\ I_L = \sqrt{3}I_\phi \angle -30°$

Δ-Y Transformations:

$$R_a = \frac{R_{ac}R_{ab}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_b = \frac{R_{ab}R_{bc}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_c = \frac{R_{bc}R_{ac}}{R_{ac} + R_{ab} + R_{bc}}$$

Y-Δ Transformations:

$$R_{ac} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_b}$$

$$R_{ab} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_c}$$

$$R_{bc} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_a}$$

$$P_T = 3|V_\phi||I_\phi|\cos\theta = \sqrt{3}|V_L||I_L|\cos\theta$$

$$Q_T = 3|V_\phi||I_\phi|\sin\theta = \sqrt{3}|V_L||I_L|\sin\theta$$

$$S_T = 3|V_\phi||I_\phi| = \sqrt{3}|V_L||I_L|$$

Transformers

Turn ratio: $a = \frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$

Equivalent circuit (referred to primary):

$$V_s' = aV_S,\quad I_s' = \frac{I_S}{a}$$

$$R_s' = a^2R_S,\quad X_s' = a^2X_S,\quad Z_L' = a^2Z_L$$

$$R_{eqP} = R_P + a^2R_S,\quad X_{eqP} = X_P + a^2X_S$$

Equivalent circuit (referred to secondary):

$$V_P' = \frac{V_P}{a},\quad I_P' = aI_P$$

$$R_P' = \frac{R_P}{a^2},\quad X_P' = \frac{X_P}{a^2}$$

$$R_{eqS} = R_S + \frac{R_P}{a^2},\quad X_{eqS} = X_S + \frac{X_P}{a^2}$$

Short-Circuit Test

$$Z_{eq} = \frac{V_{SC}}{I_{SC}},\quad R_{eq} = \frac{P_{SC}}{{I_{SC}}^2}$$

$$X_{eq} = \sqrt{{Z_{eq}}^2 - {R_{eq}}^2}$$

Open-Circuit Test

$$R_C = \frac{{V_{OC}}^2}{P_{OC}},\quad S_{OC} = V_{OC}I_{OC}$$

$$Q_m = \sqrt{{S_{OC}}^2 - {P_{OC}}^2}$$

$$X_m = \frac{{V_{OC}}^2}{Q_m}$$

Voltage Regulation

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

Efficiency $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

End of Paper